The final publication is available in: Energy Policy. 2018, 120, 58-72. 10.1016/j.enpol.2018.04.076

Elsevier Editorial System(tm) for Energy Policy

Manuscript Draft

Manuscript Number: JEPO-D-17-01722R1

Title: Can Battery Electric Light Commercial Vehicles work for Craftsmen and Service Enterprises?

Article Type: Full length article

Section/Category: Technological change

Keywords: Craftsmen & Service Enterprises; Driving pattern; Electronic travel log; Battery Electric Light Commercial Vehicles; Total cost of ownership

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CAN BATTERY ELECTRIC LIGHT COMMERCIAL VEHICLES WORK FOR CRAFTSMEN AND SERVICE ENTERPRISES?

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Abstract

Battery Electric Light Commercial Vehicles (BE-LCVs) can reduce the environmental impacts of Craftsmen and Service (C&S) Enterprises transportation. These Enterprises produce vital services, using diesel vehicles for transportation of personnel, tools and materials to worksites, thus contributing to pollution and greenhouse gas emissions. Enterprises that have taken BE-LCVs into use report practical range challenges leading to a need to reorganize their transportation activities. The driving pattern of 7 C&S enterprises operating 115 vehicles, were logged over two weeks. The potential of using BE-LCVs can be evaluated by combining the real range of BE-LCVs in Norway, with these driving patterns. Although 42% of diesel LCVs (D-LCVs) could be replaceable by BE-LCVs with a range of 170 km. Many covered so short daily distances that the transport work would only be reduced by 13%. The replaceable vehicles and transport work can increase by redistributing vehicle assignments, daytime charging, or with longer range BE-LCVs. If all year range increases to 200 kilometers, then almost all vehicles are potentially replaceable. Purchase incentives are required to unlock the potential, but may, not produce large effects until the range improves. BE-LCVs with 50% longer range enters the market in 2018, which should expand the market.

Keywords

Craftsmen & Service Enterprises; Driving pattern; Electronic travel log; Battery Electric Light Commercial Vehicles; Total cost of ownership

Abbreviations: LCV = Light Commercial Vehicle. D-LCV = Diesel powered LCV, BE-LCV = Battery Electric LCV, C&S Enterprises = Craftsmen & Service Enterprises, BEV = Battery Electric Passenger Vehicle, TCO = Total Cost of Ownership, GPS=Global Positioning System, GSM=mobile phone communication system. VAT = Value Added Tax

1 Introduction

The Norwegian fleet of vehicles contained 146006 battery electric vehicles at the end of 2017 (NPRA 2018). Of these, 139474 where passenger vehicles (BEVs), which is 5.1% of the total passenger vehicle fleet. 3481 were Light Commercial Vehicles (BE-LCVs), which is 0.7% of the fleet of LCVs, i.e. small/medium sized vans.

This article focuses on the potential for replacing Diesel LCVs (D-LCVs) with BE-LCVs in Craftsman and Service Enterprises (C&S Enterprises). The Craftsman sector consist of small enterprises offering professional vehicle based services within geographic regions at customer sites. Examples are carpenters, electricians, and service technicians. Service enterprises such as facility servicing, janitors, security and cleaning, have much of the same transportation needs.

Little research has been conducted to map Craftsmen transport activities, despite their number and vehicle biased transportation, as pointed out by Hislop and Axtell (2011). There has also not been much research on means to mitigate the transport related environmental impacts of their activities. Mobility generated by economic activity has primarily been analyzed in terms of goods transportation (Pelletier et al, 2016), commuting trips (Aguilera, 2008) and electrification of commercial and municipal fleets (Wikström et al 2014, 2016).

Workers in C&S enterprises depend on vehicles to transport personnel, tools and materials to work sites, in order to carry out their work. Unlike “white collar” professionals who can use public transport or non-motorized modes when moving between clients (in urban areas), craftsmen and service workers hardly have alternatives to vehicle based transportation (Julsrud et al, 2016). The focus must therefore be on measures to improve the environmental characteristics of the vehicles they use, and efficient administration of these vehicles in daily activities.

This article uses an exploratory approach to identify the practical and economic potential for replacing diesel LCVs (D-LCVs) with BE-LCVs in Norwegian C&S Enterprises. Electronic travel logs are analyzed to reveal the travel patterns of their vehicles. These travel logs where obtained from GPS data loggers with GSM communication, to record and send vehicle movement information to a central database. The travel patterns generated from these data logs were used to assess the potential for replacing D-LCVs with BE-LCVs. The analyzes takes into account the real world range achievable for BE-LCVs under Norwegian traffic conditions. Measures to make the transition feasible and effective is also analyzed. Interviews with early users provide information on access to charging and how these vehicles function in practice. The economic implication is analyzed using a Total Cost of Ownership (TCO) perspective. The article thus addresses the "relative advantage" and "compatibility" of innovations in Rogers' theory of diffusion of innovations (Rogers 1995), by combining user practicality with economy of use, i.e. the techno-economic potential of BE-LCVs in these user groups.

The article contributes to the ongoing research agenda on measures to make professional users transportation more sustainable, and to the more general literature on diffusion of innovations (Rogers, 1995, Geels 2012, Figenbaum 2017).

The analysis starts off in section 2 with an overview of the Norwegian electromobility context, i.e. incentives, policies and market developments for battery electric vehicles. Section 3 describes the theoretical framework used in the analysis. Section 4 presents the material, methods and calculations used. The results of the analysis are presented in Section 5 followed by the discussion in section 6 and the conclusion and policy recommendations in Section 7.

2 Norwegian context

Incentives have resulted in an unprecedented breakthrough for BEVs in the Norwegian private consumer market (Bjerkan et al 2016, Figenbaum 2017, Figenbaum et al 2015a and 2015b). Although most of these incentives also apply to BE-LCVs, a breakthrough has yet to materialize.

2.1 Clean electricity

The Norwegian electricity mix is clean, with 96% hydroelectric power (Figenbaum et al 2015b). Norway is moving towards a larger surplus in the national electricity production (NVE 2016). Electric vehicles can take up some of that surplus. Norway has no vehicle production and therefor need not take vehicle production emissions or employment into account when developing policies for greenhouse gas (GHG) emission reductions. Replacing Internal Combustion Engine Vehicles (ICEVs) running on fossil fuel with vehicles using electricity, will therefore be an effective policy to combat national GHG emissions from the transportation sector. Fossil fuel emission are eliminated, the energy efficiency is improved, and the electricity is clean. The same situation would also apply for Europe as a whole when the EU emission trading system (EU ETS) for greenhouse gases is taken into account (Figenbaum 2017). For vehicle production the picture will be more complex. The individual parts making up a vehicle and the vehicle itself may be produced inside or outside the EU ETS.

2.2 Cheap electricity, expensive diesel

The annual energy cost saving of using BE-LCVs will be much lower than that of D-LCVs due to differences in energy cost and energy efficiency. Figenbaum and Kolbenstvedt (2015) found that when BEVs replace ICEVs the cost savings is larger in Norway than in other European countries. These results are valid also for vans, but the net cost difference could be smaller as C&S Enterprises do not pay value added tax (VAT), but the energy consumption of LCVs is higher, pulling in the other direction.

2.3 BEV and BE-LCV markets

The BEV market share of the passenger vehicle market reached 18% in 2016 and 20.5% in 2017 (OFVAS 2018), as seen in figure 1. The BE-LCV market share has been stagnant around 2% since 2014. These differences can partly be explained by differences in incentives, as discussed in section 2.4, and in the technological limitations of BE-LCVs relative to the transportation needs of owners of D-LCVs. The limited availability of BE-LCV models could also have had an effect, as only four small electric vans were available in the Norwegian market in 2016, as seen in figure 2. Their main characteristics are presented in table 1 and compared with the diesel versions. They were sold in various seating, cargo and size configurations. Two of these vehicles were upgraded with a 50% range increase in 2018.

2.4 Incentives and policies

The battery electric vehicle market in Norway is heavily incentivized (Figenbaum 2017, Figenbaum et al 2015a), with the most important incentives in place over a period of 20-25 years, as seen in table 2. In the 1990s incentives were introduced to allow market experimentation, and in a period around 2000 to support an EV industry in Norway (Figenbaum 2017). From 2010 the focus shifted to climate policy goals (Figenbaum et al 2015b). The incentives are thus anchored in policies supporting climate policy targets (NTP 2016, 2017, Stortinget 2017), such as becoming a carbon neutral society by 2050.

The large market shares for BEVs has thus been the result of a long term stable national framework. The incentives have been available long enough to allow actors to take advantage of windows of opportunities that arose over the years (Figenbaum, 2017). The most important incentives have been the exemptions from the value added (2001) and registration (1990) taxes, toll road charges (1997) and the access to bus lanes (2003).

The National Transportation Plan for 2018-2027 states that only zero emission passenger vehicles, LCVs and distribution trucks shall be sold from 2025, essentially targeting a phase out of diesel and gasoline passenger vehicles and diesel vans, from the sales mix (NTP 2016). The target was confirmed by the parliament in May 2017 (NTP 2017, Stortinget 2017). If the target is to be met, only BE-LCVs or hydrogen fuel cell LCVs will have to be sold from 2025. The plan and the decision in the Parliament also revised some of the incentives, as seen in table 2.

The exemption from the registration tax has less effect on the BE-LCV market than the BEV market since D-LCVs are taxed much less than ICEVs. Other incentives may be worth more for craftsmen than for consumers because BE-LCVs are used more in cities than other vehicles, and more incentives are available in cities, such as bus lane access and free toll roads. The most important BEV incentive is however the exemption from VAT. BE-LCVs has the same exemption, but it has no effect, as professional buyers of vehicles do not pay VAT when buying vehicles.

2.5 Statistics on BE-LCV ownership and use

There were around 400.000 vans in Norway in 2014 of which 330000 had a payload below1000 kg. 72100 were registered in Oslo and 59426 in the surrounding province, Akershus (SSB 2014). The number of LCVs is growing (SSB 2016a), contributing to increased congestion and emission.

The Craftsman sector employs 9% of the workforce in Norway (SSB, 2016b) and account for 11-16 % of the vehicle based transport in Oslo, 15% in Bergen and 5% in Trondheim (Vågane et al 2014). The sector mainly uses D-LCVs. Craftsmen share of transport is increasing (SSB 2014).

Although Norway has experienced a booming electric vehicle market in recent years, the number of BE-LCVs in the vehicle fleet is still very limited, due to high costs, lower availability, limited range, long charge time and lack of a tow hook, making them less compatible with the transportation needs of LCV users. BEVs limited range is on the other hand is compatible with the needs in multi-vehicle households (Figenbaum and Kolbenstvedt 2015). Technology is however improving, and earlier studies suggest a large potential for replacing D-LCVs with BE-LCVs (Myklebust and Steen, 2012).

Craftsmen owned roughly 8% of the BE-LCVs in Norway, service enterprises (cleaning, facility services, guard companies) owned another 4% at the end of 2015 (NPRA 2016), as seen in figure 3. Fleet vehicles owned by authorities, 14% of the 2015 fleet, is also used for mobile work, such as by janitors, home nurses etc. Peugeot Partner was up to the end of 2015, Norway's bestselling BE-LCV. Renault Kangoo was the second most used vehicle followed by Nissan E-NV200. At the end of 2017, Nissan E-NV200 had become the most common BE-LCV.

According to Statistics Norway (SSB 2017), small LCVs were driven 14550 km/year in 2015. In Oslo and Akershus, the distances were 15716 and 16451 km/year, i.e. 8-13% above the national average (Ibid). Passenger vehicles were driven on average 12289 km in 2015 (Ibid).

The average age of LCVs was 8.4 years in 2015, which is shorter than passenger vehicles 10.5 years (SSB 2015b), and uncertainty battery life should be less of an issue for BE-LCV buyers than for BEV buyers.

2.6 Operation in Norwegian traffic and climatic conditions

The EU official type approval produces unrealistic emission results for ICEVs (Tietge et al 2016), and too optimistic range for BEVs (Haakana et al 2013). Figenbaum et al (2014) and Figenbaum and Kolbenstvedt (2016) nevertheless found that most BEV users, the majority being multi-vehicle households, cope fairly well with BEVs limited range and long charge times, but their achieved range is about 25% less than the type approval value in the summer, and 50% in the winter. The latter is due to the increased driving resistance of winter tires, increased air drag, and cabin heating.

BE-LCVs have the same batteries and are tested with the same method as BEVs, so range deratings should be rather equal. A 30% derating of the summer range will be used in this article, taking into account the less aerodynamic shape of BE-LCVs (table 1). BE-LCVs would then typically provide 120 km summer range, but drivers may want an additional safety margin (Figenbaum and Kolbenstvedt 2015, Franke and Krems 2012). A further 30% reduction of winter range leads to an estimate of 80 km for winter driving. Wikström et al (2016b) found that winter conditions resulted in an unjustified decrease in BEV usage in Swedish commercial vehicles and Haakana et al (2013) found that range would decrease more in severe winter conditions (-20°C) so even lower winter range estimates could be used.

Two of the marketed BE-LCVs are fast charge capable (table 1). Fast charging can mitigate some of the range concerns (Figenbaum and Kolbenstvedt 2016) and lead to better utilization of available range. Fast charging takes time and would lead to lost income, thus reducing the attractiveness. Fast charge will produce about 3-5 km of range per minute at 50 kW stations (Figenbaum 2018), depending on vehicle and season. Fast charging is slower in the winter for two reasons; (1) the batteries cannot accept full power when they are cold (Haugneland and Kvisle 2013, Nilsson 2012), and (2) the energy consumption is higher in the winter (Figenbaum and Kolbenstvedt 2016, Haakana et al 2013).

3 Theoretical framework

3.1 Diffusion of innovations

Adoption of new innovations will, according to the theory of diffusion of innovations (Rogers, 1995), depend primarily on the perceived attributes of the innovation, i.e. it's relative advantage compared to the traditional technology, it's compatibility with user needs, it' complexity, testability and observability. The relative advantage can be financial, practical, environmental or personal, giving social status or satisfaction (Figenbaum and Kolbenstvedt 2015). Examples relevant to BE-LCV adoption are: economic profitability, low initial and variable user cost, improved comfort, saving time or effort, and immediacy of reward. Some of these are influenced by technology itself (variable user cost, comfort, energy efficiency) and others by incentives (bus lane time savings).

A potential relative advantage is not of much interest if a technology is incompatible with the user's practical needs, experiences and values (Denstadli, Julsrud and Schiefloe 2017). Relative advantage and compatibility are thus interlinked when it comes to BE-LCV adoption among C&S Enterprises. These enterprises use their vehicles as a tool to be able to do their primary tasks at the premises of their customers (Julsrud et al 2016). The spatial distribution of customers varies over time, or during the day, leading to a need for LCVs to provide a flexible transportation solution (Ibid). Service Enterprises have a more predictable and predominantly local driving pattern (Ibid).

The introduction of BE-LCVs lead to less flexibility, through limited range and long charge times, and increased complexity due to the need to install charging stations. Wikström et al (2016) found that the deployment of BEVs in commercial fleets therefore needs to be followed up by information to users, an active handling of failures and promotion of usage.

Another barrier has been the limited number and types and the purchase cost of the BE-LCV models available on the market. Variable cost and the environmental impact of these enterprises transportation activities will however be reduced, leading also to advantages when taking BE-LCVs into use.

Figenbaum and Kolbenstvedt (2016) found that reduced user cost is seen as a very large advantage by consumers, and will thus be an important aspect of the total cost of ownership of BE-LCVs.

3.2 GPS tracking of vehicle movement

The potential for use of BE-LCVs in C&S enterprises can be analyzed using GPS data of vehicle movement. Passenger vehicle movement patterns have been tracked using GPS devices in the US, Italy, Sweden and Germany. Pearre et al (2011) used driving data from 484 gasoline vehicles, tracked over a period of 1-3 years, to analyze passenger vehicle driving patterns in the Atlanta (Georgia) region in the US. Among the findings was that frequency of use is not strongly related to distance per day, and there is a segment of frequently used vehicles that are only used locally, which could be an early BEV market. Björnsson and Karlsson (2014) utilized logged data over 30 days from a sample of 432 Swedish vehicles to analyze the battery requirements and economics of Plug-In hybrid vehicles. The found that commuters would be the first group for which PHEVs could become economic, and that work place charging could lead to smaller batteries and lower marginal battery cost. Khan and Kockelman (2012) used GPS data from 255 Seattle households over a period of a year to conclude that BEVs with a 100 miles' range cover travel needs of 50% of single vehicle households and 80% of multi-vehicle households, apart from four days per year. Jacobson et al (2015) compared German and Swedish vehicle movement data and concluded that the driving pattern of "second cars" in multivehicle households is better suited for BEV adoption than "first cars", and cars in single vehicle households.

Less data is available for LCVs. Gennaro et al (2014) used a sample of 28 000 vehicles travel over the month of May 2011 for the regions of Modena and Firenze, to estimate the potential for replacing vehicles with BEVs. They found that the share of commercial vehicles moving at any time was always below 16%, and that up to 25% of the vehicles could be replaceable with battery electric vehicles. Joubert and Axhausen (2011) extracted electronic travel log data from 31053 freight commercial vehicles (1.5% of the national fleet) vehicles over a period of six months in 2008, covering a province of South Africa. The analysis mainly covers freight vehicles.

The use of existing travel logs to analyze movement patterns of LCVs in a specific user group such as C&S Enterprises, as is done in this article, is a novel methodology in transportation research.

3.3 Total cost of ownership

There is a large literature on analysis of Total Cost of Ownership (TCO) of vehicles in general (see for instance: Lévay et al 2017). Nesbitt and Sperling (2001) found that fleets and private enterprises tend to take TCO into consideration when making their vehicle investments. TCO has therefore become a common method for assessing the potential for a new vehicle technology in fleets, with a number of calculation tools being available (see for instance ICVUE, Edmunds, Efleets, Automotive fleet, EECA Business). The literature on TCO is large. Palmer et al (2015) found that incentives in the UK, California and Japan led to cost parity for BEVs in these markets in 2015. Lebeu et al (2015) did calculations for D-LCVs and BE-LCVs for the Belgian market, and found that BE-LCVs could have lower TCO for longer annual driving distances. TCO will be context and country specific, heavily influenced by national policies, incentives and local energy prices. TCO only addresses the cost barrier to adoption, not organizational or practical issues. It thus complements the analysis of the practical usage potential in the assessment of the techno-economic potential for BE-LCV adoption in C&S Enterprises.

4 Material and method

4.1 Data logging

Data logs of the activity of 115 vehicles used by seven anonymous C&S Enterprises in the Oslo area, see table 3, were obtained from "TravelLog", a travel log system (GSGroup 2016). These 115 vehicles represented 0.1% of the total 2015 fleet of LCVs in the Oslo and Akershus provinces. TØI and the GS Group obtained permission to access the already stored GPS data for the vehicles operated by these companies. In some cases, the approval process involved discussions with union representatives, as these data sets raises privacy issues. The assumption is that the vehicles used diesel as a fuel, but this cannot be known for certain. The TravelLog system uses a GPS to log the vehicle position and speed. The data is sent over the mobile internet to a centralized database. Two weeks of data, covering the period 9-22. March 2015, was retrieved. The data records obtained from GS Group contained the following information:

customer	unit	Postal code	logged time	longitude	latitude	speed
1094	254179	1279	09.03.2015 00:30	10.69796944	59.47059266	0

Customer:	Anonymous code for the vehicle owner
Unit:	Anonymous code for the vehicle
Zip:	ZIP (Postal) code
logged time:	Data and time of logged data point
longitude, latitude:	Longitude and latitude of the vehicles position.
Speed:	Vehicle speed km/h

The logger unit logs the momentary status and the vehicle position and speed each km of driving and during the following events: Manoeuvers around curves, start/stop of periods of high speed, fast accelerations, start/stop of congested traffic, ignition on/off, every hour/half-hour when ignition is off. Data records can be lost if the communication with the central system is lost or the signal is weak. The dataset was cleansed for erroneous data and the longitude and latitude position was transferred to the UTM33 coordinate system to facilitate calculation of trip distances. For each vehicle (unit) the data set was split into trips. A new trip was assumed whenever there was more than 25 minutes between registered vehicle movement. The position data for the trips were transferred to maps using GIS. The distance travelled between data records was calculated and summed up to trip distances. The short data collection period could have underestimated the distance driven for privately owned vehicles, due to lower likelihood of registering long distance trips away from home. Such effects are less likely for LCVs. The effect of loss of data on the recorded driving length, due to loss of data communication between the data logger and the central database, is not known. The cleansing of data was estimated to remove less than 2% of the data points from a moving vehicle. The impact on driving length was less.

4.2 Achievable range

The achievable range is a basic determinant of the suitability of BE-LCVs for Craftsmen. Renault of Norway (Renault 2015) developed a color coding scheme to make it easier for dealers and enterprises to determine the suitability, as seen in table 4. The basis for the scheme is that the summer and winter range can be 30% and 50% less than the official range of BE-LCVs with an official range of 170 km. These estimates correspond well with the estimates private consumers have for the practical range of passenger vehicles (Figenbaum and Kolbenstvedt 2016).

The Renault color scheme has been modified for use in this article. Renaults BE-LCV has a diesel cabin heater as standard equipment, and the range will be less impacted in the winter than for BE-LCVs using electrical heaters. Each time the vehicle stops and restart, the electric heaters reheat the vehicle, thus draining the battery and an additional safety margin might be required. The problem will be more pronounced than for passenger vehicles due to more stops during the day and a larger volume to heat. Severe winter conditions can cause further range losses (Haakana et al 2013), or lead to a lower vehicle utilization in fleets (Wikström et al 2016b). The distance interval up to 80 km was thus split by the author in two intervals: (1) up to 50 km in which all vehicles are replaceable, and (2) 51-80 km where vehicles are likely replaceable, especially BE-LCVs with diesel auxiliary heaters.

4.3 Qualitative Interviews with C&S Enterprises

14 C&S Enterprises owning BE-LCVs, where interviewed in the Oslo area and in Trondheim during the period Dec 2013- 2015 (Julsrud et al 2016). Half were Craftsmen, of which 3 carpenters, 1 electrician, 1 bricklayer, 1 painter and 1 roofing enterprise. The Service-enterprises consisted of 2 security and 2 cleaning enterprises, 2 property/post services and 1 home care service. Craftsmen owned between 1 and 6 BE-LCVs, Service enterprises 3-13 BE-LCVs, the home care service 60.

The interviews were conducted at the premises of the businesses, normally with one of the leading operational managers. The interviews centered around vehicle usage in general, how the BE-LCVs are used and function in their daily business, barriers and challenges they had experienced, and the process of vehicle selection during the purchasing process. In the time frame of the interviews, few fast chargers where available. The effect of fast chargers on range and operations could therefore not be assessed.

4.4 Economics

The Craftsmen industry consists of small and medium sized enterprises, and TCO is an important parameter in their vehicle selection. TCO is therefore used as a basis for the calculation of the economics of BE-LCVs vehicles compared with D-LCVs in this article. The calculation will be limited to comparing costs that, (1) differs between the two vehicle types, and (2) are transparent to buyers. These are: the purchase price (consisting of the vehicle cost and the registration tax), the associated financial cost, energy costs and oil change cost. Residual value after 5 years is assumed to be 30% for both vehicle types. The residual value of the latest generation of BEVs introduced on the market after 2013, is similar gasoline and diesel vehicles in Norway, whereas BEVs introduced earlier experienced a large value loss due to improving technology and falling new vehicle prices (Figenbaum and Kolbenstvedt 2015, Dine Penger 2016). It is in this article assumed that the same will apply to BE-LCVs. Service cost of BE-LCVs are likely to be lower due to fewer moving parts than gasoline vehicles (UBS 2017), but are not fully transparent to users at the time of the vehicle purchase and will not be analyzed further.
Insurance cost, other servicing cost and tire cost and wear, are assumed to be the same for D-LCVs and BE-LCVs, and have not been included. The results thus show the difference in TCO between D-LCV and BE-LCV.

5 Results

5.1 Interviews

The interviewed companies owning BE-LCVs (Julsrud et al 2016), had a highly variable driving pattern, depending on assignments which sometimes changes during the day. The variability of driving could preclude replacing D-LCVs with BE-LCVs, given their limited range and long charge times.

Several craftsmen had departments only doing servicing and upgrades on existing buildings or installations. These departments had extremely variable driving needs and the interviewees stated that the BE-LCVs available in the market could definitely not be used by these Craftsmen (Julsrud et al 2016). The Craftsmen that most easily can adopts BE-LCVs, work on larger projects lasting longer time periods, making it possible to plan the transport to and from the location. The main adopters among Craftsmen have however been administrative personnel visiting work sites (Ibid).

Electricians seems to be the group of traditional Craftsmen that are most interested in taking BE-LCVs into use, and they have the fewest barriers to overcome. One interviewee said for instance that they can legally set up temporary charging facilities at work sites (Julsrud et al 2016).

The Service Enterprises, i.e. cleaning companies, estate managers and janitors, stated that they have a highly predictable and geographically confined driving pattern, which will be ideally suited for BE-LCVs. They also found it easier to find and use chargers during the day than Craftsmen do (Julsrud et al 2016). Some of the enterprises had to plan better than before and redistribute vehicles to make BE-LCVs work for them. One of these companies managed after a while of testing to replace all D-LCVs with BE-LCVs, which is in line with the finding of Wikström et al (2014) that BEV usage increases over time as experience is gathered.

5.2 LCV usage pattern

5.2.1 Geography of use

The travel patterns generated from the data-logs of the seven companies traced the road network well, as seen in the individual maps of travel in figure 4. The only exception is company B which used older data loggers, logging less activity based data than the newer loggers.

Companies A, C and E used their vehicles within a small geographical zone in the greater Oslo area, as seen in table 5 and figures 4 and 5. Companies B, D and G use their vehicles over a larger regional zone covering Eastern Norway. Company F covered large parts of Norway, departing up to 1200 km from their location. Companies F and G are fairly large C&S Enterprises. The long distance driving should therefore not preclude opportunities to replace some vehicles with BE-LCVs. These companies driving was also mainly in the greater Oslo area. Company B had few vehicles and operated in a large area, and replacing D-LCVs with BE-LCVs will thus be challenging.

5.2.2 Yearly travel

A crude estimate for yearly travel was extrapolated from the two weeks of logged data, by multiplying with a factor of 23, to 46 weeks of work, taking into account six weeks of vacation, and national holidays. Figure 6 shows the resulting estimate for the average annual driving for all the vehicles. The estimated annual average travel was 12207 km, about 24% less than the average van/small lorry according to statistics from SBB (2015). The median travel length was 10947 km.

The large share of vans with very short driving distances in the sample is surprising. Some of the companies are however located in dense parts of Oslo, potentially explaining these short distances.

Figure 7 shows the spread of the estimated number of days of usage per year per vehicle for all 115 vehicles. Half the vehicles are used the expected 181-240 days per year (a working year in Norway consists of 230 days), 22% are used on more days and 28% on fewer.

Figure 8 shows the number of days the vehicle is driven by distance travelled intervals, the number of days of driving exceeding the distance travelled intervals, and the share of days of driving that can be covered. Driving is for the total sample shorter than 80 km on 84% of days, which is rather similar to passenger vehicles (Figenbaum and Kolbenstvedt 2015). The vehicles were used less than 120 km on 94% of days. Only on 1% of the days did driving distances exceed 200 km.

5.2.3 Vehicle movement by hour of day interval

The logged movement of the 115 vehicles was scaled up by the size of the total fleet of small vans in Oslo and the surrounding province of Akershus and compared with toll road data of small vehicles (owned by enterprises) passing through the toll ring around Oslo (Vågane et al 2014). The toll road vehicle group also contained a small share of passenger vehicles owned by enterprises.

The share of vehicles travelling by hour intervals in these two data sets have the same shape, as seen in figure 9, with a morning peak at 07:00 and an afternoon peak at 15:00, correspond to the start and end of a normal working day. The peak at 11.00 is potentially due to the lunch break. At first glance at the left part of figure 9, the tail in the afternoon seems larger for the toll road data than the logged vehicles. As seen on the right, the reason is likely due to vehicles not passing through the toll road gates.

The shape of the travel demand curve, with three peaks resembles that of Gennaro et al (2014) for commercial vehicles in Modena and Firenze in Italy, apart from the share of the commercial fleet moving at any time was less than 15% in the Italian sample, half that of Oslo. Their group of "commercial vehicles" was however a much broader group. Similar data was also found by Joubert and Axhausen (2011) for South Africa.

5.2.4 Day of max travel limit replacement potential of vehicles and transport work

The maximum day of travel is the basic determinant of the immediate suitability of BE-LCVs for Craftsmen. If the travel requirement for a D-LCV on all days is less than the real world range of the BE-LCVs shown in table 1, the vehicle is replaceable. Figure 10 shows the spread of the vehicles by increasing maximum daily driving distance over the 2 weeks. The color coding comes from table 4.

28 (24%) of these vehicles are unconditionally replaceable (dark green zone). A further 12% of the vehicles (light green zone) are likely replaceable and unconditionally if they have diesel cabin heaters. 31 vehicles (27%) are potentially replaceable (yellow zone) if recharged during the day. The majority of the remaining vehicles are unlikely to be replaceable, even if they are recharged during the day.

Several of the interviewees (Julsrud et al 2016) stated that all their vehicles would be replaceable if the al year real traffic range of BE-LCVs is increased to 200 km. 15-20% of the 115 vehicles were occasionally driven over 200 km per day, so the data does provide some support for the interviewees statement.

Many vehicles are replaceable but the effects on transport work will be less. Figure 11 shows the percentage of the 115 vehicles by maximum day of travel intervals, transport work by day of travel distance intervals, and transport work by maximum day of travel distance intervals.

The split of the driving by all vehicles (red color) by all days of travel within the distance intervals, is the theoretical maximum potential to replace the total transport work for all the vehicles, if the vehicles were fully interchangeable and charged overnight. If all transport could have been replaced with BE-LCVs on days of travel less than 80 km, then 42% of the transport work could be replaced. The vehicles are owned by different companies and thus not interchangeable so that number is unrealistic.

When only vehicles never exceeding the maximum day of travel intervals are replaced (which could be possible for each company), the potential for replacing vehicles (blue color) will be much larger than the potential for replacing transport work, (grey color). The figure shows that with a limit of 80 km driving on the maximum day of travel, 42% of vehicles will be replaceable but only 13% of the transport work. A 50% increase in real world range, which will be achievable with next generation BE-LCVs, coming on the market in 2018, will increase the share of replaceable vehicles to 68% and the share of replaced transport work would more than triple to 41%, which fits well with the statement of several BE-LCV owners (Julsrud et al 2016) that the range was "almost good enough", but a bit more would make the vehicles much more useful.

36% of the vehicles drive occasionally above 120 km, accounting for 59% of the total transport work. To reach into the potential of replacing these vehicles, three approaches could be possible, as discussed in section 5.3: 1) charging during the day, 2) new technology with longer range, 3) redistribute travel between vehicles so that fewer vehicles are used on long distances.

5.3 Increasing potential by reducing range challenges

5.3.1 Redistributing travel

The potential for replacing transport work of D-LCVs with BE-LCVs may be enlarged if the Enterprise's transport activities can be redistributed between vehicles, so that BE-LCVs are used for the short distance trips they are capable of, and D-LCVs for long distance driving.

In the company having the largest vehicle fleet, company G, 11 out of 49 vehicles was driven more than 120 km on the day of maximum travel distance (red zone, see table 4). Redistributing the long distance driving between vehicles would allow that number to be reduced to three, and yellow zone vehicles to five, as seen in table 6. There is thus a large theoretical potential to increase use of BE-LCVs by optimizing the driving between vehicles. The optimization would likely involve redistributing assignments between craftsmen, so that some specialize on doing the work closest to the base using BE-LCVs, while those with assignments further away use D-LCVs. Swapping vehicles might be difficult if the tools and equipment in vehicles are personalized (Julsrud et al 2016).

Wikström et al (2016) found that matching driving needs with BEVs characteristics is a requirement for successful deployment. The interviewed companies stated that they had indeed found a need to redistribute travel or swap vehicles after they had taken BE-LCVs into use, to make efficient use of them (Julsrud et al 2016). Most BE-LCVs were in reality used for field support by work supervisors in the Craftsmen enterprises (Julsrud et al 2016), as it is easier for these users to swap vehicles.

Company G had at the outset a rather unusual driving pattern, with many vehicles covering very short distances. It is located in a fairly central location in Oslo. Detailed GPS data indicates that the company has work in the immediate neighborhood of the company office. The very short distances covered by the vehicles in the green zone make the company a candidate for introducing BE-LCVs.

If the range of BE-LCVs increase to 120 km, the gain of redistributing travel between vehicles is reduced from 15 vehicles and 4980 km, to 8 vehicles and 2564 km.

5.3.2 Opportunity and overnight charging

A normal full recharge of an empty battery takes about 8-11 hours depending on vehicle type. On 95% of the days the overnight stop time exceeded 11 hours, enough for BE-LCVs to be fully recharged. The stop pattern reveals opportunities for charging during the day, which could increase the daily range and the number of replaceable vehicles and transport work. Each hour of normal charging (16A/230V, 2.8 kW usable) increase range by 15 km in the summer and 7 km in the winter.

The total average workday stop time can thus lead to a range increase of about 85 km in the summer, and 40 km in the winter, increasing the number of definitively replaceable vehicles to 50 and likely replaceable vehicles to 23. The same effect could be achieved with fast chargers, but the cost of time, i.e. lost income, makes fast charging less attractive for C&S Enterprises than for consumers.

Public normal chargers are of little use to this user group. They have to park in close proximity to the customer's sites, and it would be pure chance if a public charger would be available there. The interviewees stated that while it would often be possible to charge at customer's sites, they found it awkward to ask for permission to do so (Julsrud et al 2016).

5.3.3 New technology enabling longer range

Battery electric vehicles are under rapid development, with several long range models introduced in 2017, such as the Opel Ampera-e with 520 km range and the Renault ZOE with 400 km range. BE-LCVs lags behind passenger vehicles in development. Renault upgraded however the Kangoo BE-LCV at the end of 2017 to a range of 270 km which is 50% more than the old model (Renault 2018) and Nissan will in 2018 relaunch the E-NV200 with 50% longer range (Nissan 2018). These vehicles will enable travels of 120 km all year. The yellow zone vehicles in figure 10 will thus become replaceable with these BE-LCVs. Peugeot and Citroën continues selling their vehicles having 170 km of range. Renault still do not offer fast charging.

5.4 Economics of BE-LCVs

The economics of BE-LCV usage was analyzed for the situation in 2015-2016, by calculating the difference in the cost of ownership of D-LCVs and BE-LCVs over 5 years[2].

The purchase cost difference between an BE-LCV and a D-LCV was about 4500-7500 Euro when the registration tax was included and VAT excluded, and 6000-8500 Euro excluding all taxes. The cost of ownership, taking into account value loss, fuel/electricity cost, financial cost and annual oil change cost, was almost the same over 5 years for D-LCVs and BE-LCVs. The added purchase cost of the BE-LCV, was partly or fully offset by lower energy costs, exemption from the registration tax, avoidance of oil change cost and reduced annual taxes, as seen in figure 12.

Two of the BE-LCVs had lower costs than the diesel version. Local incentives, such as savings in free toll road and parking costs, and time savings using bus lanes, on average summed up to 1500 Euro/year/BEV for private consumers (Figenbaum and Kolbenstvedt 2016) and could tip the scale for BE-LCVs having a higher TCO than diesel versions.

The life of the battery is a crucial input into the calculation. Modern BEVs are sold with an eight year, 70% battery capacity warranty on the batteries (Source: Vehicles importers web sites). BE-LCVs were sold with a five-year warranty, but will likely last longer than eight years, being the same type as those in BEVs. Some interviewed companies stated that the life of D-LCVs in craftsman enterprises can be as short as five years (Julsrud et al 2016). Battery life is thus less of an issue for Craftsmen. BE-LCVs could however have a higher loss of value if managers put a risk premium on the uncertainty about second hand value and battery life. The market may then not respond to a favorable TCO.

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[2] Value Added Tax excluded as companies are eligible for a 100% VAT refund. Value loss of the vehicles has in all cases been set to 70% over 5 years. Annual oil change cost 80 Euro. Further assumptions are a mileage of 14800 km/year. The interest rate is 4%. The electricity consumption is assumed to be 240 Wh/km (20% more than BEVs). Diesel consumption is assumed to be 40% higher than the type approval value (Tietge et al 2016) and a 2016 diesel price of 0.93 Euro/liter, an electricity price of 0.073 Euro/kWh (SSB 2017a, 2017b), both with all taxes included apart from VAT. 1 Euro= 10 NOK.

The economics of using the two 2018 vehicles with 50% longer range is also showed in figure 12. These vehicles are more equal substitutes to D-LCVs, with much less technological risk for users. For the Renault vehicles the TCO is lower for the electric than for the diesel version. For the Nissan vehicles, it is the opposite, but the BE-LCV price is for a launch model, with a lower priced model coming later. TCO of BE-LCVs will be higher than for D-LCVs in countries without incentives. Norwegian electricity rates are among Europe's lowest and the diesel fuel cost among the highest (Figenbaum et al 2015), making Norway stand out further as a beneficial place for BEVs and BE-LCVs.

6 Discussion

A significant breakthrough for BE-LCVs has not happened yet in Norway in spite of incentives that have made the BEV market boom. Economy of use should not be a big barrier, as the Norwegian incentives evens out the TCO of BE-LCVs and D-LCVs. The biggest barrier seems to be that much of C&S Enterprises transportation is incompatible with BE-LCVs, leading to an uncertainty about usability. C&S Enterprises that already owned BE-LCVs did say that BE-LCVs are economic to use, but range is critically low in the winter. These often small companies stated that they need the flexibility D-LCVs offer, to be able to adapt to changing assignments. Some service enterprises with limited operational radius saw a potential to replace their entire fleet (Julsrud et al 2016). They also found it easier to charge during the workday, and their customer base is fairly stable (Ibid).

The theoretical potential for replacing D-LCVs with BE-LCVs is large, but the impact on transport work is limited by the fact that low mileage vehicles are easiest to replace. If a company can redistribute vehicles within the fleet, then more vehicles and more of the transport work will be replaceable. Realizing the full redistribution potential will obviously not be possible, as it is not known if these anonymous vehicles are truly interchangeable. It might as an alternative, be possible to swap assignments rather than vehicles. C&S Enterprises that already used BE-LCVs had adapted their driving patterns to extend the usability.

Another option is to charge during the day, which theoretically could increase the number of replaceable vehicles by 74%. Three of the four BE-LCVs on the market can be fast charged. The impact of fast charging could however not be assessed as few fast chargers were in operation when the interviews were done. The number of fast chargers has increased rapidly since then, but BE-LCV sales remain low.

The data logs used in the analysis only covers two weeks of driving and were scaled up to a year. For a passenger vehicles owned by a consumer, this would have led to a tendency to underestimate long distance driving, as the vehicle would be more likely to be at home for shorter data logging periods. This issue should not be as relevant for BE-LCVs used by C&S Enterprises in limited geographical zones.

BEV technology offers the best user economy compared to D-LCVs when the vehicles are used as much as possible, due to their low energy cost per km. Figure 13 shows the 115 vehicles estimated annual driving distance versus their maximum length of travel on any day. Using the range limits from table 4 and estimates of saved energy costs, the vehicles are placed within colored zones according to the techno-economic replacement potential. The vehicles within the areas marked with green and blue colors, are the ones that are economical to replace with BE-LCVs, if BE-LCVs have a cost premium of up to 10000 Euros over the diesel version.

The smallest green area is compatible with BE-LCVs having an all year range of 80 km, representing a viable BE-LCV market of 5%, which is not far from their real market share (figure 1).

A central element in theory of diffusion of innovations (Rogers 1995) is compatibility with user needs, and this case illustrates that point. Re-invention, i.e. vans with longer range, will be able to unlock more of the potential. The second largest green area will be reachable when BE-LCVs with 50% longer range becomes available in 2018. The potential can also partly be achieved with BE-LCVs with 80 km range, if the transportation can be reorganized, or when using daytime charging.

The blue area contains vehicles that are unlikely to be replaceable with BE-LCVs until the technology improves beyond the 2018 level. Daytime charging of these 2018 vehicles could lead to some adoption within the blue stipled area, potentially increasing the number of replaceable vehicles to 78%, the share of km driven to 60%, and improve the TCO. The upper range boundary of 200 km was stated by users to lead to a potential to replace all their vehicles (Julsrud et al 2016). More than 90% of the 115 LCVs could then be replaceable. Such long range BE-LCVs are technically feasible as seen by developments in the passenger vehicle market, but TCO might not be favorable.

The orange area offers some fuel savings and is within all BE-LCVs range capabilities. Within the red area there are many easily replaceable vehicles, but replacement will not be economic.

Finally, the interviewees (Julsrud et al 2016) stated that they also need larger BE-LCVs, and vehicles with tow hooks to transport materials to work sites. Tow hooks will become available on two 2018 year models. (Renault 2018, Nissan 2018) and larger BE-LCVs are scheduled to come on the market in 2018/2019, but their range will be 200 km, limiting their usability.

7 Conclusions and Policy Implications

While BE-LCVs is a promising technology from an environmental point of view, their limited range led to practical challenges for C&S enterprises. Norway is one of the most BE-LCV friendly country in the world. Purchase incentives, reduced annual tax and cheaper energy costs, make these vehicles competitive on a TCO basis with D-LCVs. In addition, comes user privileges, such as exemptions from toll roads, free parking, and time savings using bus lanes. Yet the market for BE-LCVs has been very slow compared to the consumer BEV market, likely due to a lack of compatibility between the short range and long charge time these vehicles currently offer, and the variable transportation needs of Craftsmen adapting to customer needs. This situation is rather typical for new technology. In the beginning of the diffusion process there are often drawbacks of an immature technology, leading to adoption barriers.

Adaptations to user habits can expand the potential in the initial introduction phase, as indicated by research on diffusion of innovations (Julsrud et al 2016). The potential for replacing D-LCVs with BE-LCVs can be expanded if the transport assignments within a vehicle fleet is rescheduled, so that fewer vehicles are used on long distance trips, but this reduces flexibility which is highly valued be these users.

Charging while at customer work sites to expand range was seen as feasible, and could provide about the same range increase as rescheduling vehicles, but deemed an unattractive intrusion on customers. Fast charging might be feasible but will lead to a loss of income while charging. Service enterprises can more easily introduce BE-LCVs, operating in confined geographical regions with a stable customer base. They also find it easier to charge during the day.

The Norwegian experience indicate that incentives may not lead to significant uptake of BE-LCVs, until the range barrier has been reduced. Users needed to lay down considerable effort to make the first generation of vehicles work for them. Cost was not the main barrier as TCO of BE-LCVs matched the TCO of D-LCVs. In countries without incentives and less favorable energy costs, the TCO will be at a disadvantage and the diffusion of BE-LCVs among C&S Enterprises will likely not start.

Anonymous data from data loggers have proven to provide valuable insights into the vehicle usage of C&S Enterprises, and the potential to replace D-LCVs with BE-LCVs. A surprisingly small sample was enough to generate a driving activity per hour of day very similar to that of vehicles passing the toll road gates in Oslo. The travel logs also revealed a large action radius of some vans, but most are used locally.

Acknowledgement

This paper is based on data collected in the Crafttrans project carried out between 2012 and 2016 with financial support from the Research council of Norway (grant number 227068), the Norwegian Public Roads Administration, the Municipality of Oslo and Renault of Norway. MoZEES, a Norwegian Centre for Environment-friendly Energy Research (FME), co-sponsored by the Research Council of Norway (project number 257653) and 40 partners from research, industry and public sector, supported the work.

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Tables

Table 1 Characteristics and prices (2015) of BE-LCVs and D-LCV counterparts. Source: importers web sites.

	Peugeot Partner L1	Peugeot Partner Edition L1	Nissan E-NV200	Nissan NV200 (WS comfort)	Renault Kangoo Z.E.	Renault Kangoo
Propulsion system	Electric	Diesel Basic 1.6 Blue HDI 75 hp	Electric	Diesel working star edition 110 hp	Electric	Diesel 1.5 dCi 75 hp
Sales price	21580 Euro	18785 Euro	20990 Euro	20881 Euro	19990 Euro	21014 Euro
Price excl. vat/ registration tax	21500 Euro	13990 Euro	20990 Euro	15088 Euro	19990 Euro	15717 Euro
Registration tax	0 Euro	1731 Euro	0 Euro	2347 Euro	0 Euro	1824 Euro
VAT (if appl.)	0 Euro	3064 Euro	0 Euro	3446 Euro	0 Euro	3473 Euro
Transport volume	3.3 m^3	3.3 m^3	4.2 m^3	4.2 m^3	3 m^3	3 m^3
Max load	695 kg	785 kg	588 kg	677 kg	625 kg	595 kg
Seats	3	3	2	2	2-3	2-3
Range	170 km		170 km		170 km	
Charge time	6-11 hours		7-12 hours		6-8 hours	
Fast charge	80%/30min		80%/30min			
CO_2 emission		112 g/km		130 g/km		112 g/km
Energy consumption		4,3 l/100 km	130 Wh/km	4,9 l/100 km	155 Wh/km	5.2 l/100 km

Table 2 BEV incentives in Norway.

Incentives	Introduced	BEV buyers - relative advantage	Future of the incentives.	Effect on BE-LCV market
Fiscal BEV incentives: Reduction of purchase price/yearly cost gives competitive prices				
Exemption from registration tax	1990/1996	The tax is based on ICEV emissions and weight. Example taxes: VW Up 3000 €. VW Golf: 6000-9000 €.	To be continued until 2020.	Reduced advantage because the tax rates are lower. Typical tax for small BE-LCV is 2000-2500 €.
VAT exemption	2001	Vehicles competing with BEVs are levied a VAT of 25% on sales price minus registration tax.	To be continued until 2020.	Most buyers have refund of VAT and thus no advantage of this incentive
Reduced annual vehicle license fee	1996/2004	BEVs and hydrogen vehicles 52 € (2014-figures). Diesel rate: 360-420 € with/without particulate filter.	To be continued indefinitely	Same rates apply as for passenger vehicles
Reduced company car tax	2000	The company-car tax is 50% reduced, but BEVs have seldom been used as company cars.	This incentive was revised to 40% reduction from 2018	Not relevant for vehicles owned by enteprises
Direct BEV subsidies to users: Reduction of variable costs and help solving range challenges				
Free toll roads	1997	In Oslo-area saved costs are 600-1 000 € per year. Some places savings exceed 2 500 € for commuters	Law revised so that fees for battery electric vehicles in toll roads and ferries will be decided by local governments, up to a maximum rate of 50% of the ICEV rate.	Potentially larger effect on BE-LCVs driven more during the day, especially in cities.
Reduced fares on ferries	2009	Similar to toll roads, users save money using main road car ferries.		Unknown
Financial support for normal charging stations	2009	Reduce investors risk, reduce users range anxiety, expand vehicle usage.	A national plan for charging infrastructure shall be developed as for EU countries.	Charge at vehicle base/worksite, little need for public stations.
Financial support for fast charge stations	2011	More fast-charging stations influences BEV km driven & market shares.	Government support programme (run by ENOVA) to establish fast charging along major transport corridors and in municipalities without fast chargers. City fast charging left to commercial actors.	Possible to reach customers further away, but maybe not economic due to high time cost.
User privileges: Reduction of time costs and providing users with relative advantages				
Access to bus lanes	2003/2005	BEV users save time driving to work in the bus lane during rush hours.	Local authorities have been given the authority to introduce restrictions if BEVs delay buses. Oslo area has for some bus lanes a requirement to be more than one person in the vehicle during the rush hours.	Larger effect because time saved can be used to serve customers
Free parking	1999	Users get a parking space where these are scarce or expensive and save time looking for a space.	Before 01.01.2017 a national regulation. After that, local authorities have been given the authority to introduce rates up to 50% of the rate for ICEVs. 27 municipalities still have free parking, 33 have introduced charges. The rest are mainly municipalities where free parking is available for everyone.	Less effect, must park where the work site is, and max time constraint on public parking spaces is an issue.
Free charging (some places)		Not regulated by national law, but often bundled with free municipal parking	Local authorities and parking operators decides whether this incentive will continue. Often bundles with free parking.	Most owners have electricity available at work site. Cost of charging is low

Table 3 Vehicles and companies in the sample

Company	Number of vehicles	Postal code	Municipality
A	4	1279	Oslo
B	7	0598	Oslo
C	7	0283	Oslo
D	15	0373	Oslo
E	4	3472	Røyken ~20 km South-west of Oslo city centre
F	29	1477	Lørenskog ~15 km East of Oslo city centre
G	49	0585	Oslo

Table 4 Colour coding of vehicles and evaluation of possibility to replace the D-LCV by a BE-LCV (having the characteristics in table 1), by the day of maximum driving distance over the two-week period (authors assessment based on a Renault of Norway scheme).

Distance driven day of maximum driving	Original Renault scheme	Revised evaluation of potential to replace D-LCVs with BE-LCVs (authors assessment)
Always under 51 km	Vehicles can be replaced	All vehicles can be replaced
51-80 km		Vehicles can likely be replaced, all vehicles if diesel heater installed
81-120 km	Vehicles can potentially be replaced, depending on road-type, driving style, speed, cargo, topography, temperature, charging	Potential depend on road-type, driving style, speed, cargo, topography, temperature, charging
Over 120 km	Not compatible unless possible to charge during day	Not compatible unless possible to charge during day

Table 5 Geographical spread of travel by each company.

Company	Widest distance from office	Geographical zone
A	60 km	Larger Oslo Area, south to Moss
B	200 km	Eastern Norway
C	20 km	Larger Oslo Area
D	220 km	Eastern Norway (mainly south part)
E	50 km	Larger Oslo Area
F	1200 km	Eastern, Middle and North Norway
G	200 km, 250 km including Sweden	Eastern Norway + trips to Western-Sweden

Table 6 Transport work over 2 weeks, per vehicle category and estimated distance per year per vehicle in each category (red, yellow, green zones according to table 4), before and after a theoretical redistribution of transport between vehicles owned by company G.

	Before redistributing travel			After redistributing travel		
	# Vehicles	Total transport work 2 weeks, km	Average per year per vehicle km	# Vehicles	Total transport work 2 weeks, km	Average per year per vehicle km
Red zone # vehicles, >120 km	11	8 499	18 500	3	5 935	47 500
Yellow zone # vehicles, 80-120 km	12	6 046	12 100	5	3 630	17 400
Green zones # vehicles <80 km	26	3 649	3 400	41	8 629	5 100

Figures

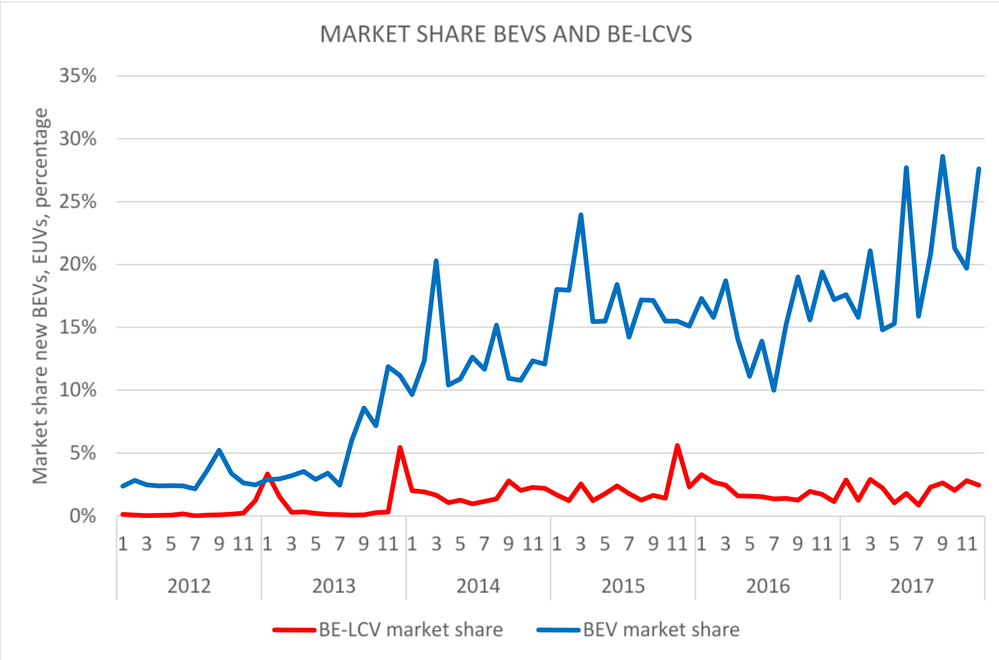


Figure 1. BEV and BE-LCV market shares in Norway, 2012-2017. Source: Data from www.ofvas.no 2018.

Figure 2 BE-LCVs in the Norwegian market, left to right: Renault Kangoo, Nissan E-NV200, Peugeot Partner, Citroën Berlingo, Source: Importers/manufacturers web pages

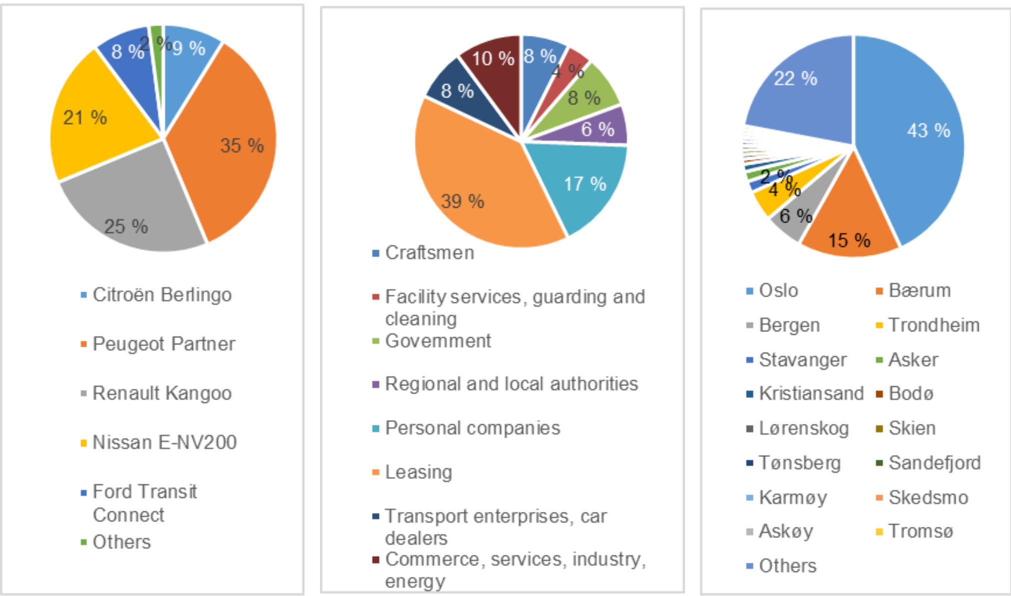


Figure 3 Types of battery electric utility vehicles in the fleet at the end of 2015, and the split on owner types and where they are registered. Source: Data on registered vehicles from the Norwegian Public Roads Administration 2016.

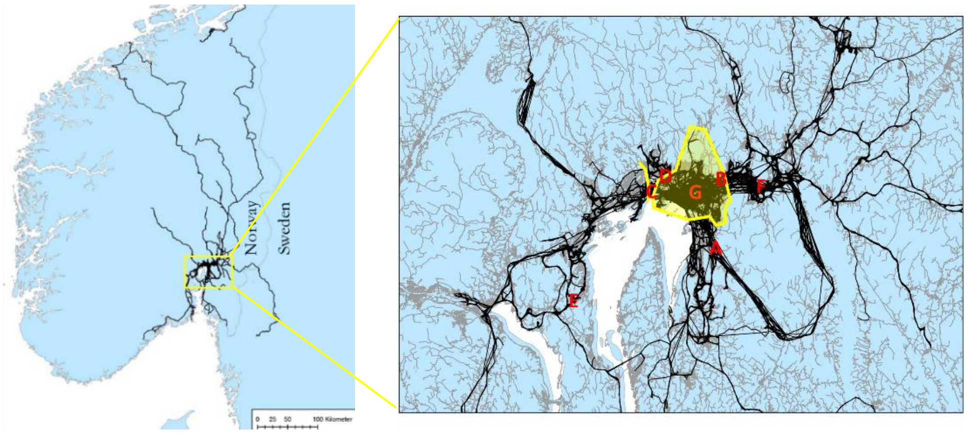


Figure 4. Distribution of driving by Enterprises A-G on a national scale (left), and within the greater Oslo area (right). Yellow lines (right chart) shows the approximate position of toll roads around Oslo, Red letters marks the approximate position of enterprises A-G based on the postal code.

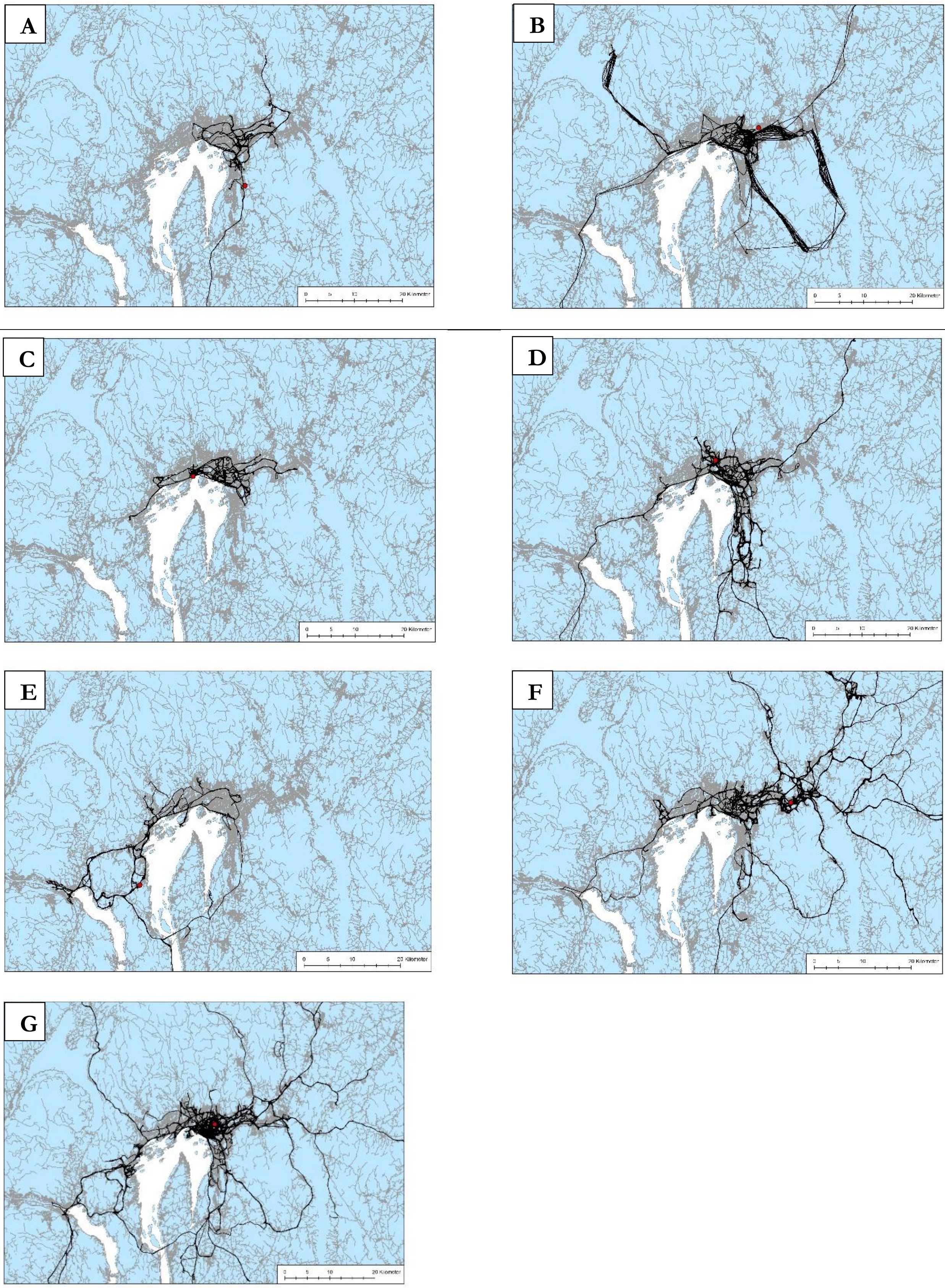


Figure 5. Travel pattern of Enterprises A-G in the greater Oslo area. Red dots mark the approximate position of the Enterprises, based on the area covering the postal number of the enterprise location.

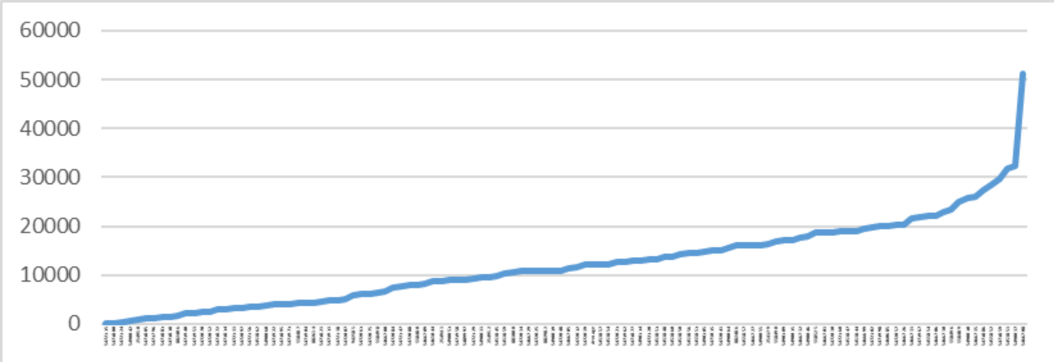


Figure 6 Estimated yearly driving based on 2 week of data logging. Y-axis Km/year.

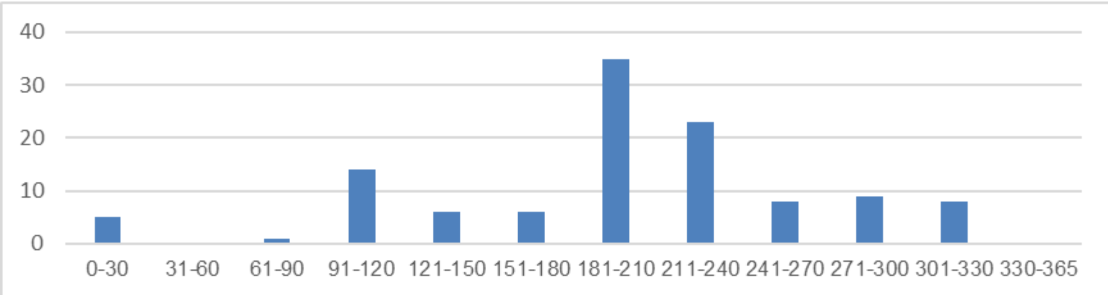


Figure 7 Number of vehicles (Y-axis) per interval of days of usage (x-axis) per year.

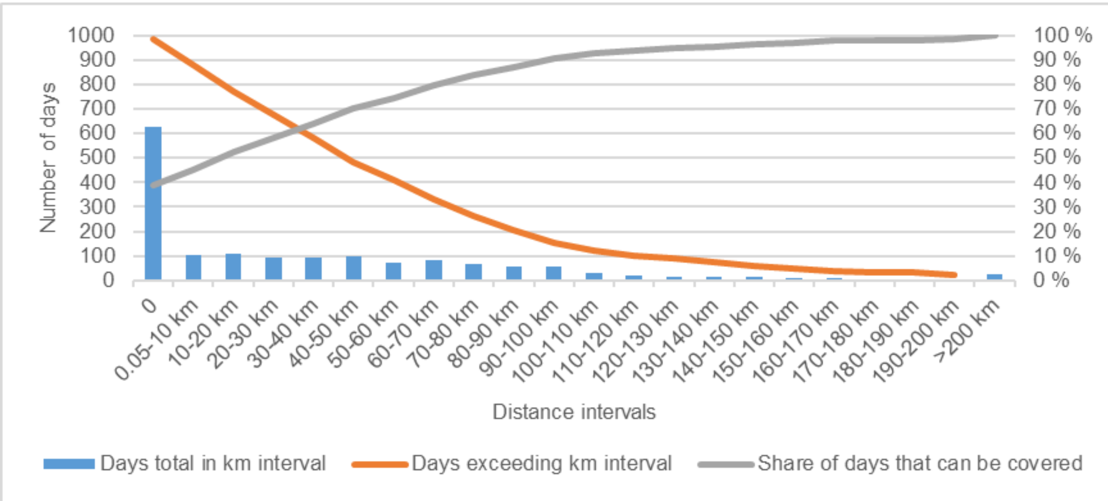
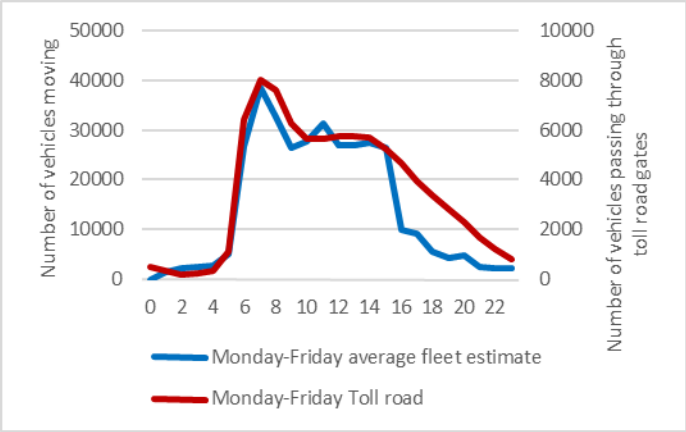


Figure 8 Days of travel by distance intervals, days of travel exceeding distance interval and share of days that can be covered.



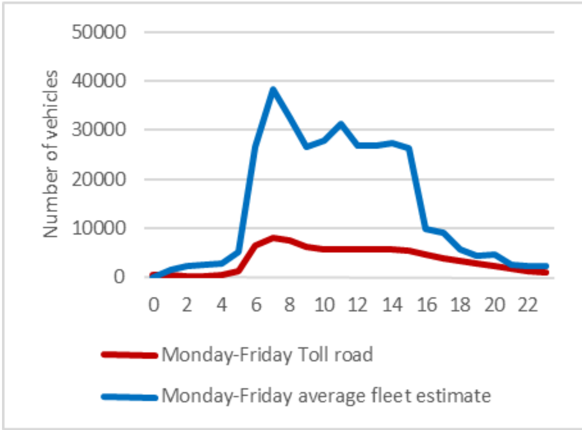


Figure 9 Travel activity per hour, average Monday-Friday. Left: Number of vans passing the toll gates of Oslo on the right axis, estimated travel of vans scaled up from 115 logged vans to the total fleet on the left axis. Right: vehicles passing toll gates and travel of logged vehicles on the same scale, number of vehicles.

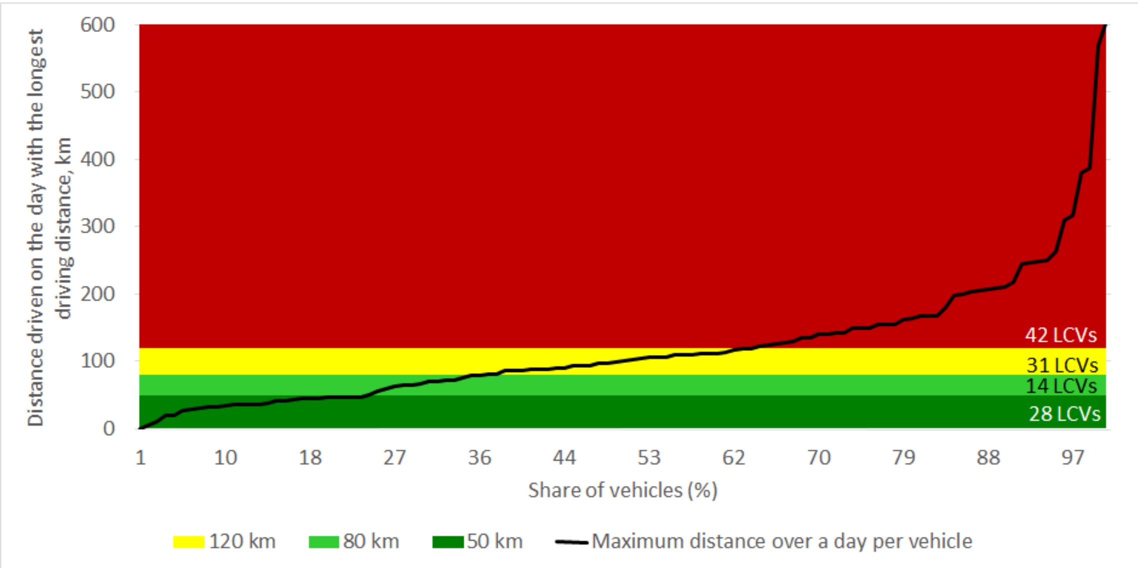


Figure 10 Potential share of D-LCVS replaceable with BE-LCVs having a range of 170 km, displayed by increasing length of travel (black line) on the day of maximum travel over the 2 weeks of 9-22. March 2015. Dark green: Fully replaceable, Light green: Likely replaceable. Yellow: Replaceable if the vehicle can be recharged during the day. Red: Non-replaceable.

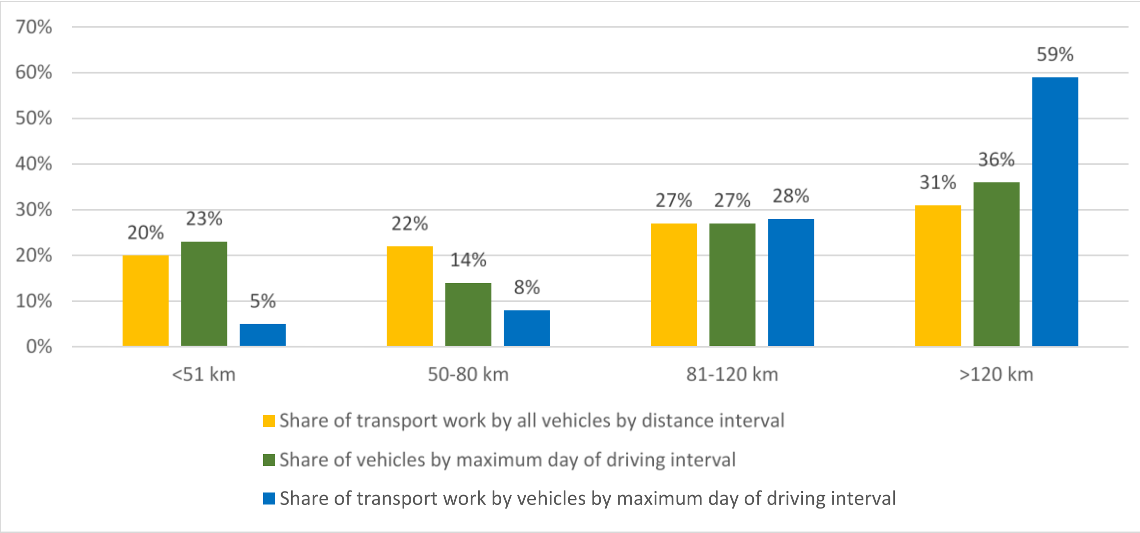


Figure 11. Percent of vehicles by maximum day of travel length interval, transport work by all vehicles by daily distance interval, transport work by vehicles by day of maximum day of travel length interval.

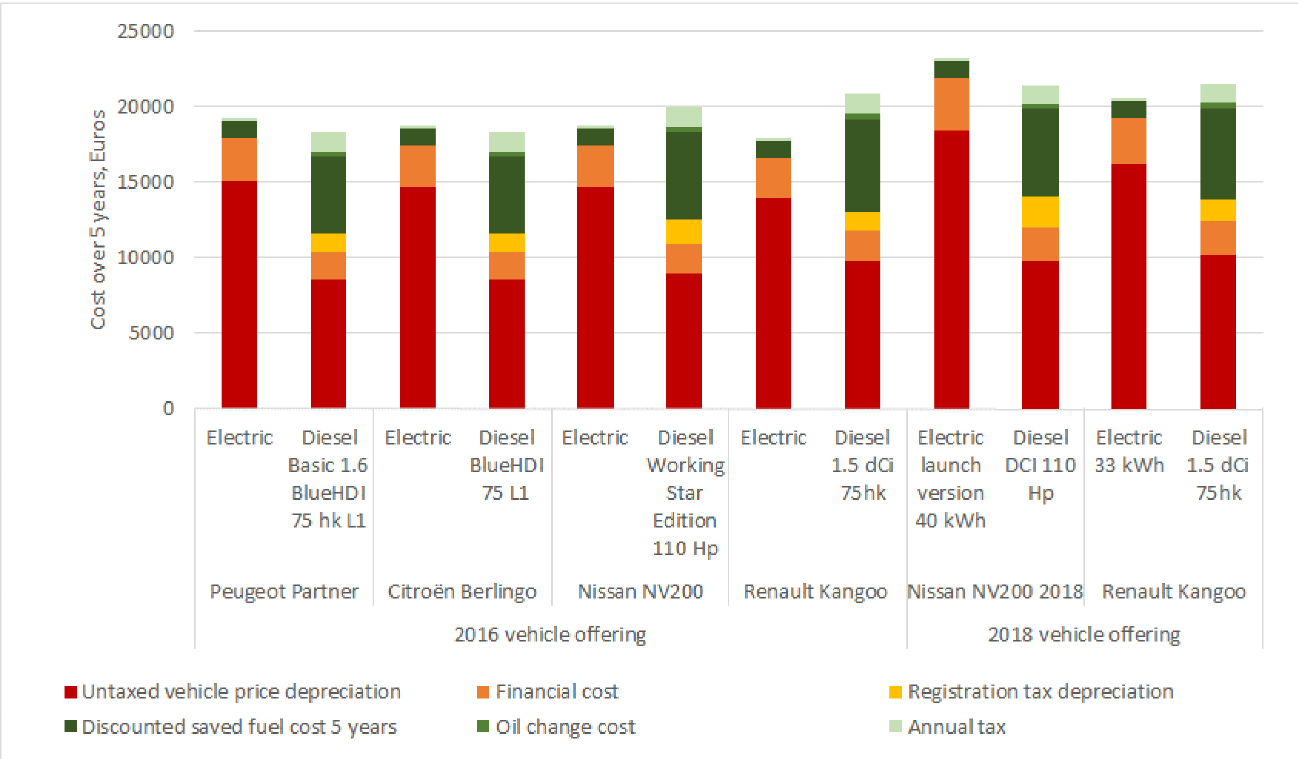


Figure 12 Economics of BE-LCVs in 2016 and two examples from 2018, Cost of Ownership over five years, without VAT. The depreciation resulting from purchase cost minus residual value after five years have been split into untaxed vehicle price loss and registration tax loss. Costs not included in the figure are assumed to be identical for all vehicle types, i.e. maintenance, tires, insurance, although maintenance outside of oil change is likely lower for BE-LCVs.

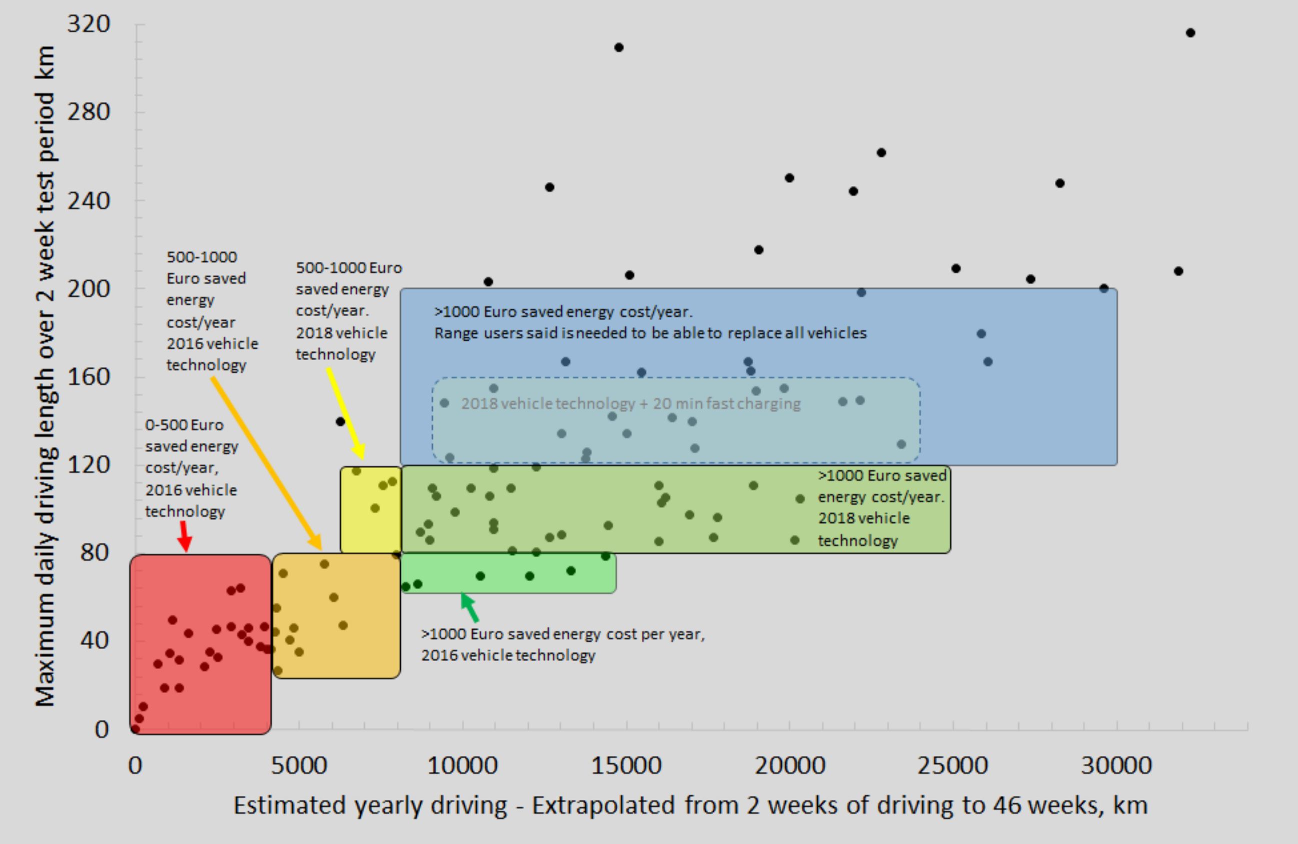


Figure 13 Economics and practicality of BE-LCVs. Three vehicles had more than 320 km driving on max day (not shown)

Reviewer #4: The article "Can battery electric ....." is interesting to read. The language used is good and reader has almost no difficulty in understanding. However, following important things needs to be reviewed.

1. Line 4-10 of introduction: "which is 4% of the total fleet" is misleading.
The text has been revised and updated so as to show numbers of BEVs and BE-LCVs registered at 31.12.2017, and the respective share of all registered passenger vehicles and LCVs.

2. Theoretical framework needs to be well presented. In the current form, it is less.
The theoretical framework has been totally rewritten, describing three topics: (1) diffusion of innovations, (2) GPS tracking of vehicle movement and (3) Total cost of ownership. The article focus is thus on establishing the practical techno-economic potential of BE-LCVs under Nordic conditions for C&S Enterprises.

3. Consistently, author should incorporate more references.
New references have been added throughout the article.

Finally, my recommendation is to suggest author "corrections"
I *am not sure what is meant here. I have updated according to the comments above. In addition, the following has been revised: Updated some of the graphics. I have included assessment of the effect of the improved range of models coming on the market in 2018. Text has been reviewed for clarity. Conclusions and Policy recommendations has also been updated. All costs have been converted to Euros. The text has been compressed to keep within 8000 Words.*

Highlights

- Craftsmen and Service Enterprises use diesel light commercial vehicles for transportation needs
- Battery Electric Light Commercial vehicles can reduce the environmental impact of their transport
- Limited range lead to loss of transportation flexibility, constituting a large barrier to adoption
- Range issues can be reduced by rescheduling vehicles, charging during the day, new technology